Analytical Modeling and Simulation of MEMS Devices

Synopsis

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Submitted by

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Abstract

Microelectromechanical Systems (MEMS) are referred to as microsystems in Europe and micromachines in Japan. MEMS Devices ranges in size from a few micrometers to millimeters. MEMS provide very good scope for sensing physical, chemical and biomedical parameters in an efficient way which could be integrated with VLSI chips.

MEMS utilize the mechanical properties of several elements such as cantilever, beams, combdrive, membrane, reservoirs and channels etc. In order to optimally utilize the properties of these micro mechanical elements, the mechanical behavior of elements in presence of parameters has to be study in detail.

The objective of this research work is to develop new application specific analytical models for various MEMS Structures with the aim to enhance the device performance. Simulation tools such as Comsol, Ansys, Intellisuite may be used to simulate analytical models.

Keywords: MEMS Devices, Microstructures, Analytical models.

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Chapter 1

Introduction

1.1 Introduction of MEMS

During last one decade, MEMS (Micro Electro Mechanical Systems) have been identified as one of the most promising technologies of 21st Century, where mechanical and electrical components are integrated together in one chip in the form of a single integrated device or an Electro-Mechanical System. These small devices of the order of few microns have the ability to sense, control and actuate on the micro scale and can further generate effects on the macro scale. Current MEMS devices include accelerometers, gyroscopes, biosensors , etc., and thus can be implemented in the production many high commercial volumes, viz., airbag sensors, inkjet printer heads, computer disk drive read/write heads, projection display chips, blood pressure sensors, microvalves, optical switches.

MEMS technology has thus continuously been revolutionizing both the industrial and consumer products by combining silicon based microelectronics with micromachining technology. Its technique and micro-systems based devices have the potential to dramatically affect our lives and the way we live. If semiconductor micro-fabrication was seen to be the first micro-manufacturing revolution, MEMS is assumed to be the second one.

MEMS, an acronym that originated in the United States, is also referred to as Microsystems Technology (MST) in Europe and Micromachines in Japan. Regardless of the terminology, the uniting factor of a MEMS device is the way it is fabricated. While the device electronics are fabricated using 'computer chip' IC technology, the micromechanical components are fabricated by sophisticated manipulations of silicon and other substrates using micromachining processes. Processes such as bulk and surface micromachining, as well as high-aspect-ratio micromachining (HARM) selectively remove parts of the silicon or add additional structural layers to form the mechanical and electromechanical components. While integrated circuits are designed to exploit the electrical properties of silicon, MEMS takes advantage of either silicon's mechanical properties or both its electrical and mechanical properties. In the most general form, MEMS consist of mechanical microstructures, micro-sensors, micro-actuators and microelectronics, all integrated onto the same silicon chip. This is shown schematically in Figure 1.

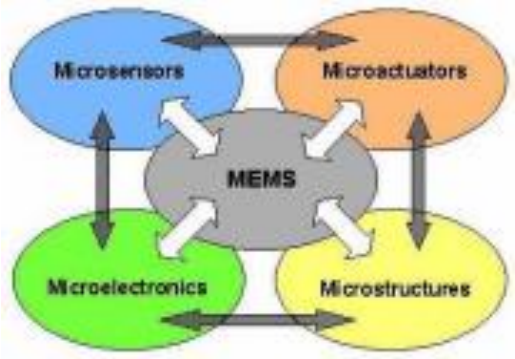

Figure1. Schematic illustration of MEMS components.

Micro-sensors detect changes in the system's environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomena. In a Microelectronics process this physical quantity information is implemented in signaling the micro-actuators to react and thus create some form of changes to the environment. MEMS devices are very small; their components are usually microscopic. Levers, gears, pistons, as well as motors and even steam engines have all been fabricated by MEMS. From a very early vision in the early 1950's, MEMS has gradually made its way out of research laboratories and into everyday products. In the mid-1990's, MEMS components began appearing in numerous commercial products and applications including accelerometers used to control airbag deployment in vehicles, pressure sensors for medical applications, and inkjet printer heads. Today, MEMS devices are also found in projection displays and for micro-positioners in data storage systems. However, the greatest potential for MEMS devices lies in new applications within telecommunications (optical and wireless), biomedical and process control areas.

MEMS has several distinct advantages as a manufacturing technology. In the first place, the interdisciplinary nature of MEMS technology and its micromachining techniques, as well as its diversity of applications has resulted in an unprecedented range of devices and synergies across previously unrelated fields (for example biology and microelectronics). MEMS on account of its batch fabrication techniques enables many components and devices to be manufactured with increased performance and reliability, combined with the obvious choice of reduced physical size, volume, weight and cost. Thirdly, MEMS provides the basis for the manufacture of products that are not feasible through other processing techniques. These factors make MEMS potentially a far more pervasive technology than integrated circuit microchips. However, there

are many challenges and technological obstacles associated with miniaturization that are still required to be addressed and overcome before MEMS can realize its overwhelming potential.

1.2 Definitions and Classifications

Although MEMS is also referred to as MST (microsystems technology), strictly speaking, MEMS is a process technology used to create these tiny mechanical devices or systems, and as a result, it is a subset of MST. Micro-optoelectromechanical systems (MOEMS) is also a subset of MST and together with MEMS forms the specialized technology fields using miniaturized combinations of optics, electronics and mechanics. Both their microsystems incorporate the use of microelectronics batch processing techniques for their design and fabrication. There are considerable overlaps between fields in terms of their integrating technology and their applications and hence it is extremely difficult to categorize MEMS devices in terms of sensing domain and/or their subset of MST. The real difference between MEMS and MST is that MEMS tends to use semiconductor processes to create a mechanical part. In contrast, the deposition of a material on silicon for example, does not constitute MEMS but is an application of MST.

Transducer

A transducer is a device that transforms one form of signal or energy into another form. The term transducer can therefore be used to include both sensors and actuators and is the most generic and widely used term in MEMS.

Sensor

A sensor is a device that measures information from a surrounding environment and provides an electrical output signal in response to the parameter it measured. Over the years, this information (or phenomenon) has been categorized in terms of the type of energy domains but MEMS devices generally overlap several domains or do not even belong in any on e category.

These energy domains include:

- Mechanical - force, pressure, velocity, acceleration, position
- Thermal - temperature, entropy, heat, heat flow
- Chemical - concentration, composition, reaction rate
- Radiant - electromagnetic wave intensity, phase, wavelength, polarization
  Reflectance, refractive index, transmittance
- Magnetic - field intensity, flux density, magnetic moment, permeability

• Electrical - voltage, current, charge, resistance, capacitance, polarization

Actuator

An actuator is a device that converts an electrical signal into an action. It can create a force to manipulate itself, other mechanical devices, or the surrounding environment to perform some useful function.

1.3 History

The history of MEMS is useful to illustrate its diversity, challenges and applications. The following list summarizes some of the key MEMS milestones.

1950's

1958 Silicon strain gauges commercially available

1959 "There's Plenty of Room at the Bottom" – Richard Feynman gives a milestone presentation at California Institute of Technology. He issues a public challenge by offering $1000 to the first person to create an electrical motor smaller than $1/64^{th}$ of an inch.

1960's

1961 First silicon pressure sensor demonstrated

1967 Invention of surface micromachining. Westinghouse creates the Resonant Gate Field Effect Transistor, (RGT). Description of use of sacrificial material to free micromechanical devices from the silicon substrate.

1970's

1970 First silicon accelerometer demonstrated

1979 First micromachined inkjet nozzle

1980's

Early 1980's: first experiments in surface micromachined silicon.

Late 1980's: micromachining leverages microelectronics industry and widespread experimentation and documentation increases public interest.

1982 Disposable blood pressure transducer

1982"Silicon as a Mechanical Material". Instrumental paper to entice the scientific community– reference for material properties an d etching data for silicon.

1982 LIGA Process

1988 First MEMS conference

1990's

Methods of micromachining aimed towards improving sensors.

1992 MCNC starts the Multi-User MEMS Process (MUMPS) sponsored by Defense Advanced Research Projects Agency (DARPA)

1992 First micromachined hinge

1993 First surface micromachined accelerometer sold (Analog Devices, ADXL50)

1994 Deep Reactive Ion Etching is patented

1995 BioMEMS rapidly develops

2000 MEMS optical-networking components become big business

1.4 MEMS Applications

Automotive	**Electronics**	**Medical**	**Communications**	**Defense**
Internal navigation sensors	Disk drive heads	Blood pressure sensor	Fiber optic network components	Munitions guidance
Air conditioning compressor sensor	Inkjet printer heads	Muscle simulators & drug delivery systems	RF Relays, switches and filters	Surveillance
Brake force sensors & suspension control accelerometers	Projection screen televisions	Implanted pressure sensors	Projection displays in portable communications devices and instrumentation	Arming systems
Fuel level and vapour pressure sensors	Earthquake sensors	Prosthetics	Voltage controlled oscillators	Embedded sensors
Airbag sensors	Avionics pressure sensors	Miniature analytical instruments	Splitters and couplers	Data storage
“Intelligent” tyres	Mass data storage systems	Pacemakers	Tuneable lasers	Aircraft control

Table 1.1: Different applications of MEMS Devices.

New MEMS Applications

The experience gained from these early MEMS applications has made it an enabling technology for new biomedical applications (often referred to as BioMEMS) and wireless communications comprised of both optical, also referred to as micro-optoelectromechanical systems (MOEMS), and radio frequency (RF) MEMS.

i) BioMEMS

Over the past few years some highly innovative products have emerged from BioMEMS companies for revolutionary applications that support major societal issues including DNA sequencing, drug discovery, and water and environmental monitoring. The technology focuses on microfluidic systems as well as chemical testing and processing and has enabled devices and applications such as 'lab-on -a-chip', chemical sensors, flow controllers, micronozzles and microvalves to be produced.

ii) MOEMS

Optical communications has emerged as the only practical means to address the network scaling issues created by the tremendous growth in data traffic caused by the rapid rise of the Internet. Current routing technology slows the information (or bit) flow by transforming optical signals into electronic information and then back into light before redirecting it. All optical networks offer far superior throughput capabilities and performance over traditional electronic systems.

The most significant MOEMS device products include waveguides, optical switches, cross connects, multiplexers, filters, modulators, detectors, attenuators and equalizers. Their small size, low cost, low power consumption, mechanical durability, high accuracy, high switching density and low cost batch processing of these MEMS-based devices make them a perfect solution to the problems of the control and switching of optical signals in telephone networks.

iii) RF MEMS

RF MEMS is one of the fastest growing areas in commercial MEMS technology. RF MEMS are designed specifically for electronics in mobile phones and other wireless communication applications such as radar, global positioning satellite systems (GPS) and steerable antenna.

The technology includes circuit tuning elements (capacitors/inductors, resonators, filters, microphones and switches). These low-loss ultra-miniature and highly integrative RF functions can and will eventually replace classical RF elements and enable a new generation of RFdevices.

1.5 MEMS Market

Product Types	1996 Units (millions)	$ (millions)	2002 Units (millions)	$ (millions)
HDD heads	530	4500	1500	12000
Inkjet print heads	100	4400	500	10000
Heart pacemakers	0.5	1000	0.8	3700
In vitro diagnostics	700	450	4000	2800
Hearing aids	4	1150	7	2000
Pressure sensors	115	600	309	1300
Chemical sensors	100	300	400	800
Infrared imagers	0.01	220	0.4	800
Accelerometers	24	240	90	430
Gyroscopes	6	150	30	360
Magnetoresistive sensors	15	20	60	60
Microspectrometers	0.006	3	0.15	40
TOTAL	**1595**	**$13,033**	**6807**	**$34,290**

Table 1.2: MEMS Devices market Scenario

1.6 Miniaturization Issues

MEMS is not about miniaturization; it is a manufacturing technology used to create tiny integrated microdevices and systems using IC batch fabrication techniques. Similarly, miniaturization is not just about shrinking down existing devices; it's about completely rethinking the structure of a microsystem. In order to manufacture a successful MEMS device basic physics and operating principles including scaling laws need to be fully understood and appreciated at both a macro and microlevel. Sometimes no advantages in terms of performance, size/weight, reliability and cost can be gained with a MEMS device. Increased surface areas(S) to volume (V) ratios at micro scales have both considerable advantages and disadvantages.

Some of these microlevel issues include:

- Friction is greater than inertia. Capillary, electrostatic and atomic forces as well as stiction at a micro-level can be significant.
- Heat dissipation is greater than heat storage and consequently thermal transport properties could be a problem or, conversely, a great benefit.
- Fluidic or mass transport properties are extremely important. Tiny flow spaces are prone to blockages but can conversely regulate fluid movement.
- Material properties (Young's modulus, Poisson's ratio, grain structure) and mechanical theory (residual stress, wear and fatigue etc.) may be size dependent.
- Integration with on-chip circuitry is complex and device/domain specific. Lab-on-a-chip system components may not scale down comparably.
- Miniature device packaging and testing is not straightforward. Certain MEMS sensors require environmental access as well as protection from other external influences. Testing is not rapid and is expensive in comparison with conventional IC devices.
- Cost – for the success of a MEMS device, it needs to leverage its IC batch fabrication resources and be mass-produced.

1.7 Research Aim

To study and develop appropriate application specific analytical models for various MEMS devices and to estimate the performance of each of these by implementing these models over various available simulation tools.

1.8 Research Objectives

1. Study and review the mechanism of various types of MEMS Microstructures, Devices and the already designed various analytical models.
2. Develop a new application specific analytical model for various MEMS Structures with the aim to enhance the device performance.
3. Implementation of above developed analytical model with various Simulation Tools like Ansys, Comsol, Intellisuite etc.
4. Evaluate the performance of simulated model in terms of the end user requirements.

Chapter 2

Review of MEMS microstructures and Devices

2.1 MICROCANTILEVER SENSOR

2.1.1 INTRODUCTION

In recent years, researchers have reported a new type of mechanical sensor for chemicals and biological molecules [Hyung Joon Kim et al., (2003) and Arunava Majumdar, et al., (2004)]. In particular, it was discovered that when chemical or biological reactions occur on one side of a micro cantilever beam, they produced a bending moment that deflected the cantilever (Figure 2.1). A micro cantilever beam is made of some structural material such as silicon or silicon nitride (SiNx) and is usually coated with another material on one side of the cantilever for biomolecular functionalization or passivation. Using appropriate surface chemistry, one can immobilize some probe biomolecules on one side of the cantilever. When analyte molecules specifically bind to the probe molecules, the molecular binding between the probe and target molecules causes the surface stress change on the side of the cantilever. The change generates sufficient torque to bend the micro cantilever beam, which can be detected either optically or electrically.

Researchers have demonstrated the technology can be used for chemical sensing, DNA recognition, and detection of virus particles [Min Yue et al., (2004) and T.L. Porter et al., (2003)]. When occurring on a cantilever, the reaction-induced free energy reduction on one cantilever surface is balanced by the strain energy increase due to bending, such that at equilibrium the free energy of the whole system reaches the minimum [Hagan *et al.* (2002)]. In other words, the penalty of increasing the strain energy must be compensated by a larger reduction in free energy due to the reaction, reflecting the interplay between mechanics and chemistry.

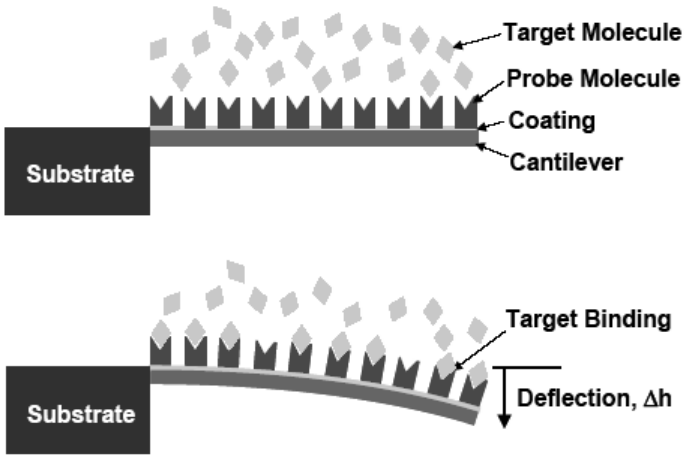

Figure 2.1: Specific biomolecular interactions between target and probe molecules alter intermolecular interactions within a self-assembled monolayer on one side of a cantilever beam. (This can produce a sufficiently large surface stress to bend cantilever beam and generate motion.)

The cantilever bending can be construed as a measure of free energy reduction due to the chemical reaction on one surface [Hagan *et al* (2002)]. What is worth noting is that because free energy reduction is common for all reactions, the cantilever-based sensing is a universal platform for studying all reactions. Furthermore, the technique does not require attachment of labels to the biomolecules.

2.1.1.1 THEORETICAL BACKGROUND

Micro cantilever sensors can be operated in two different modes: resonance response variation and cantilever bending. The following provides some theoretical background for these modes and explain why cantilever bending was chosen to build the biological assays in this work.

2.1.1.2 Resonance Response Variation Approach:

Shifts in cantilever resonance frequency can be used to detect changes in cantilever mass or spring stiffness, both of which can change due to molecular adsorption. A rectangular diving-board shaped cantilever is used as an example in the following to discuss the sensitivity of mass detection. The spring constant of a rectangular cantilever for a point load at the end is [Sarid (1994)]:

$$k = \frac{F}{z} = \frac{Ewd^3}{4L^3} \tag{2.1}$$

where F is the point load applied at the end of the cantilever, and z is the resulting end deflection, E is the Young's modulus of elasticity for the cantilever material and w, d, L are the width, thickness, and length of the cantilever, respectively. The fundamental resonance frequency can be written as

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m^*}} = \frac{1}{2\pi}\sqrt{\frac{k}{0.24m_b}} \tag{2.2}$$

Where m^* and mb are the effective mass and the real mass of the cantilever respectively. For a rectangular diving-board shaped cantilever, $m^* = 0.24mb$. Surface adsorbed molecules can change the effective mass of the cantilever as well as its spring constant. Thus the change of resonance frequency is given as:

$$df(m^*,k) = \left(\frac{\partial f}{\partial m^*}\right)dm^* + \left(\frac{\partial f}{\partial k}\right)dk = \frac{f}{2}\left(\frac{dk}{k} - \frac{dm^*}{m^*}\right) \tag{2.3}$$

In certain cases when adsorption is uniform over the entire cantilever, the spring constant of the cantilever can change due to a number of causes, such as changes in the elastic constant of the surface film and dimensional changes of the cantilever or coatings. However, one could also design cantilevers with localized adsorption areas at the terminal end of the cantilever so that the contribution from differential surface stress (the dk/k term in Esq. 3-3) can be minimized and neglected. The mass sensitivity of a sensor is usually defined as

$$S_m = \lim_{\Delta m \to 0} \frac{A}{f}\frac{\Delta f}{\Delta m} = \frac{A}{f}\frac{df}{dm} \tag{2.4}$$

Where Δm and dm are normalized to the active sensor area of the device and A is the area of the cantilever.

It is noteworthy that, in real measurement system, the practical sensitivity can be affected by another parameter, the quality factor (Q-factor). Q-factor of a resonator is a measure of the spread of the resonance peak, Δf, and is thus related to energy loss due to damping ($Q = f0 / \Delta f$). The lower the Q-factor, the more damped the oscillator. The Q factor depends on parameters such as cantilever material, geometrical shape, and the viscosity of the medium. Typically, the Q-factor of a rectangular silicon cantilever in air is approximately 30. However, in liquids the Q-factor decreases by a factor of 10 making the resonance peak very broad. Therefore, measurements of adsorbed mass based on resonance frequency variation suffer from low resolution in liquid environment. As all of biological molecular bindings naturally occur in liquid environment, cantilevers operated in resonance response mode are not suitable for developing biomolecular binding assays.

2.1.1.3 Adsorption-Induced Cantilever Deflection Approach

As molecular reactions on a surface is ultimately driven by free energy reduction of the surface, the free energy reduction leads to a change in surface tension or surface stress. While this produces no observable macroscopic change on the surface of a bulk solid, the adsorption-induced surface stresses are sufficient to bend a cantilever if the adsorption is confined to one surface of the beam. However, adsorption-induced forces should not be confused with bending due to dimensional changes such as swelling of thicker polymer films on cantilevers. Sensitivities of adsorption-induced stress sensors can be three orders of magnitude higher than those of frequency variation mass sensors (for resonance frequencies in the range of tens of kHz).Moreover, the static cantilever bending measurement is ideal for liquid-based applications where frequency-based cantilever sensors suffer from huge viscous damping.

Using Stoney's formula, the deflection at the end of a cantilever, z, can be related to the differential surface stress, σ, as [Stoney (1909)]

$$z = \frac{3\sigma(1-\nu)}{E}\left(\frac{L}{d}\right)^2 \qquad (2.5)$$

Where *d* and *L* are the cantilever beam thickness and length, respectively; *E* and υ are the elastic modulus and the Poisson ratio of the cantilever material. Equation 3-5 shows a linear relation between cantilever bending and differential surface stress. For a silicon nitride cantilever of 200 μm long and 0.5 μm thick, with *E* = 3.20×1011 N/m2 and υ = 0.27, a surface stress of 0.9 mJ/m2 will result in a deflection of 1 nm at the end, which can be easily detected using an optical readout system similar to that of atomic force microscope (AFM). Thus, cantilever bending has been chosen to build the biological assays in this work.

2.1.2 CANTILEVER DEFLECTION DETECTION METHODS

Micro sized cantilevers bring several advantages, the most important being the measurement of micro cantilever deflection with sub-angstrom resolution. They can be divided in optical and electric methods and can be implemented in cantilever based biosensors.

Optical Lever:

The most diffused method in AFM is the so-called beam bounce or optical lever technique. The visible light from a low power (few mW) laser diode is focused on the free apex of the cantilever which acts as a mirror. In order to increase reflectivity, commercial cantilevers for AFM are often coated by a thin layer of gold. The reflected beam hits a position sensitive photo detector or a split photo detector as schematically described in figure 2.2. When the cantilever bends, the reflected laser light moves on the photo detector surface. The distance traveled by the laser beam is proportional to the cantilever deflection and linearly magnified by the cantilever photo detector distance as the arm of a lever. Higher the deflection, larger will be the distance traveled by the laser beam, which is detected by the photodiode assembly. In order to get the deflection in terms of nanometers one has to do calibration for which the cantilever is pressed against the hard surface with a known distance and record the corresponding change in the photo detector voltage output is recorded. It should be noted that, with this method, the cantilever bending rather than

its displacement, i.e. the slope at the point where the laser hits the cantilever, is actually measured [R Raiteri et al., (1995)].

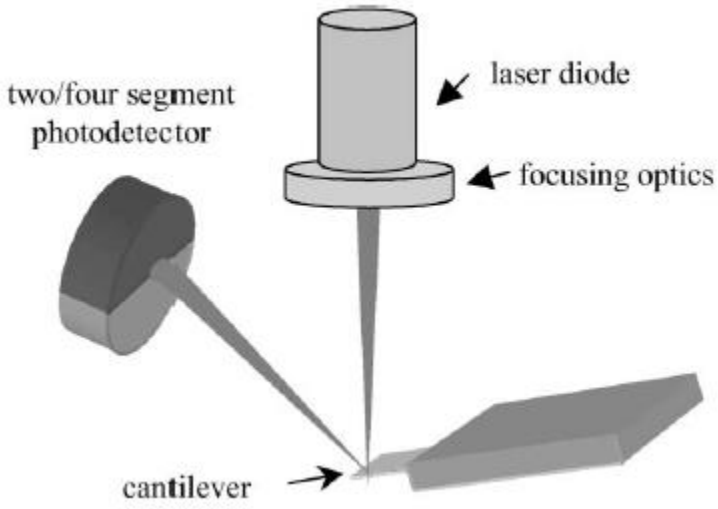

Figure 2.2: Optical lever deflection detection method

Interferometry

This method is also an optical deflection method but it uses interference of a referenced laser beam with the one reflected by the cantilever. This method is a very sensitive method and it provides a direct and absolute measurement of the displacement. However there are a few technical problems with this method. Light has to be brought close to the cantilever to get enough reflected light and for this purpose, the cleaved end of an optical fiber is positioned few micrometers away from the free end of the cantilever. This positioning of the fiber is a demanding task. Measurements in the liquids are generally less sensitive and also absolute deflection is defined within a single wavelength. By Interferometry, Resolution in the range of 0.01 A^0 is achievable.

An alternative approach is used in miniaturized accelerometers for physical sensing. In this approach, interdigitated cantilevers are used as an optical diffraction grating. In this case, the reflected laser light forms a diffraction pattern whose intensity is proportional to cantilever deflection [D.Rugar et al., (1988) and S.R.Amnalis et al., (1996)].

Capacitive Sensor

When the distance between the two plates of a parallel plate capacitor changes, its capacitance gets altered. In this types of sensors cantilever is used as one of the plated of a parallel plate capacitor. When the cantilever experiences a deflection, the distance between two plate changes resulting in the change in capacitance. The value of a capacitor is determined by the following equation

$$C = \varepsilon_0 \varepsilon_{mat} \left[\frac{\text{Plate Area}}{\text{Distance Between Plates}} \right] \quad (2.6)$$

Where ε_0 and ε_{mat} are dielectric constants of vacuum and the material between the capacitor plates, respectively. If more than one material is present between the plates, the term ε_{mat} is replaced by an effective ε_0 value that depends on the individual ε materials are present between the plates of a capacitor, the resultant value, to a first approximation, is given by the following equation

$$\frac{1}{\varepsilon_{eff}} = \frac{Vol_1}{\varepsilon_1 . Vol_{total}} + \frac{Vol_2}{\varepsilon_2 . Vol_{total}} \quad (2.7)$$

Where Vol_1 and Vol_2 represent the volumes of materials 1 and 2, respectively, and $\varepsilon_1$and ε_2 represent their respective dielectric constants. Vol_{total} is the total volume of space between the two plates of the capacitor. Thus, when biological material is introduced in between the capacitor plates, the effective dielectric constant and the capacitance value will change [Anupama Balasubramanian, et al., (2005)]. This change in capacitance value can be used to detect the presence of the virus. However this method is not suitable for large displacements and also in aqueous conditions because of the faradic currents between the capacitor plates [R Raiteri et al., (1995)].

2.2 Piezoresistive/Piezoelectric cantilevers

When a piezoresistive material like doped silicon is strained, it changes its electrical conductivity. As a result, these sensors turn out to be the most suitable devices for monitoring surface stresses. Piezoresistive sensors can also be incorporated inside a cantilevered structure. Their resistivity can be easily measured with a simple circuit employing a wheatstone's bridge. Recent improvements allowed the fabrication of thin and passivated resistors into the cantilever structure. This allows their use in electrolyte solution by avoiding Faradic currents. The output is measured as a differential signal between a sensing piezoresistive material and a reference one.

Piezoresistive detection, compared to the optical one, shows several advantages: no expensive and macroscopic optical components and no time consuming laser alignment are needed; read out electronics can in principle be integrated on the same C-MOS fabrication technology. Optical techniques can be subjected to artifacts due to changes in the optical properties of the medium surrounding the cantilever, e.g. a change in the refractive index when exchanging two different solutions, which can move the laser spot on the photo detector surface. Piezoresistive detection does not suffer from this problem and can work in nontransparent solutions.

Piezoresistive cantilevers also offer the possibility to vary the temperature of their surface by simply increasing the current through the resistor layer. And this local control of temperature can also be helpful for breaking the ligand-receptor binding, thus regenerating the sensing layer. On a negative note, cantilever cross-sectional structure is complex as the resistor must be embedded into the dielectric layer to operate in electrolytes. As a consequence, there are technological limits in fabricating thin, highly sensitive cantilevers for this purpose [R Raiteri et al., (1995)].

Chapter 3

Research Methodology and Design approach

3.1 Overview of Problem:

An approximate model is known as analytical when it is entirely described using mathematical equations.These equations represent the physical characteristics (Mechanics, Thermal, Electrical Electrotechnics, Electromagnetism, Matérials, Pneumatics, Hydraulics, Thermodynamics, etc…) and economic of the device.

The motive of research work is to design and develop new analytical model for MEMS devices with the aim to enhance device performance.

3.2 Research Design & approach:

The major steps involved in this research report are summarized in Figure 3.1 and are detailed below.

- To study and review the mechanism of various types of MEMS Microstructures and Devices.
- To review various MEMS technologies available for the fabrication of MEMS Microstructures.
- To study and review the already designed various analytical models and to develop new application specific analytical models for various MEMS Structures with the aim to enhance the device performance.
- To study the implementation of various Simulation Tools and to perform a pilot study trial of the developed analytical models with the aim to implement these simulation software to investigate the application of MEMS Structure efficiently in fulfilling the end user requirements.

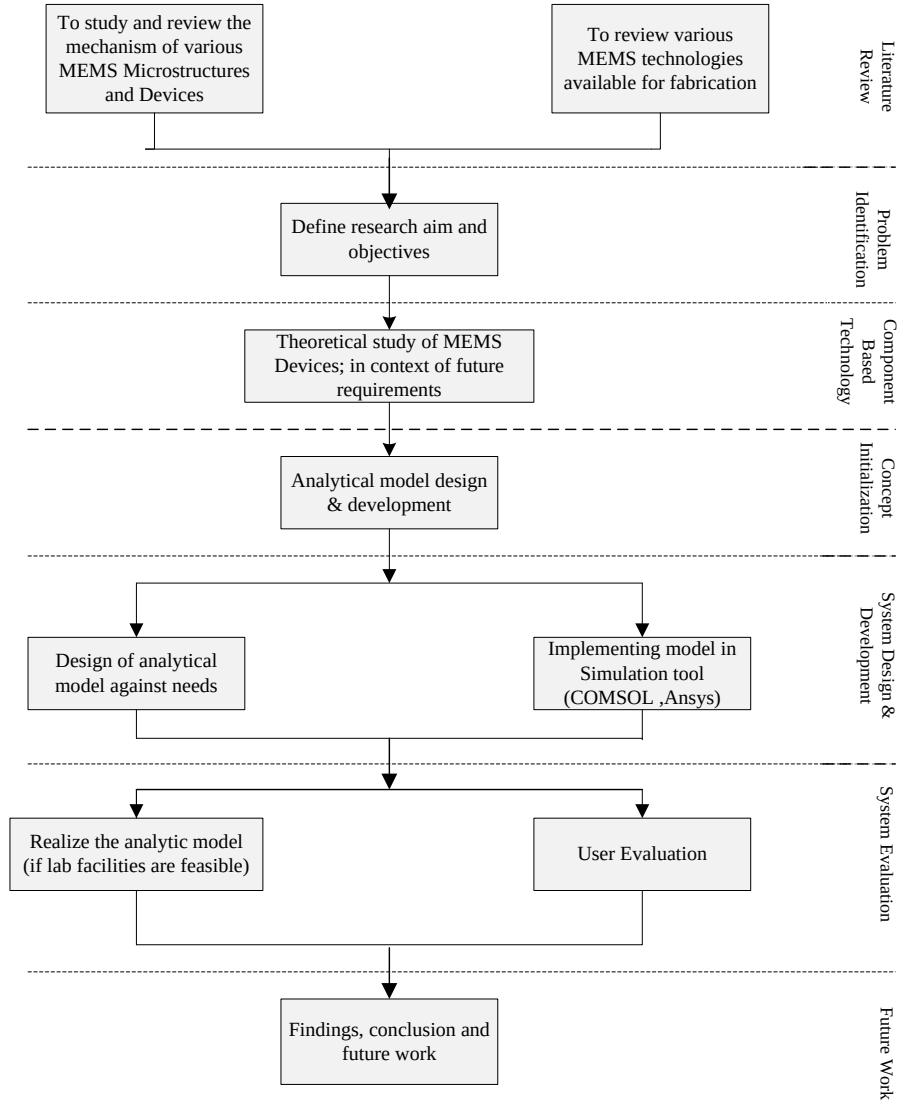
To study and review the mechanism of various MEMS Microstructures and Devices
To review various MEMS technologies available for fabrication
Literature Review
Define research aim and objectives
Problem Identification
Theoretical study of MEMS Devices; in context of future requirements
Component Based Technology
Analytical model design & development
Concept Initialization
Design of analytical model against needs
Implementing model in Simulation tool (COMSOL ,Ansys)
System Design & Development
Realize the analytic model (if lab facilities are feasible)
User Evaluation
System Evaluation
Findings, conclusion and future work
Future Work

Figure3.1: Overview of research design approach and methodology

Thesis time frame:

S.No.	Research work	Time Required
1.	Literature Review	6 months
2.	Problem identification	2 months
3.	Component based technology	4 months
4.	Concept initialization	6 months
5.	System design and development	6 months
6.	System evaluation	6 months
7.	Thesis binding and Publications	6 months

Table 3.1: Thesis time frame

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